AGRO PRODUCTIVIDAD

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Fire effect on the diversity of forest species in a medium superennifolia forest of Mexico

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ABSTRACT

Objective: Evaluate the effect of fire on natural regeneration and forest species diversity in a medium superennifolia forest in southeastern Mexico.

Design/methodology/approach: Natural regeneration was classified into three height categories (0 to 30 cm, 31 cm to 1 m and 1 to 3 m) and trees in three forest sites burned and unburnt by fire.

Results: A total of 1193 individuals belonging to 69 species in 29 taxonomic families were recorded. Regeneration from 0 to 30 cm presented significant differences in species diversity in unburnt forest sites, while in regeneration from 1 to 3 m in burned forest sites.

Limitations on study/implications: These types of studies are a first approximation to natural regeneration after a fire in tropical forests, so it is important to maintain permanent sites to monitor the recovery of ecosystems and thus be able to establish management strategies for the restoration of these ecosystems.

Findings/conclusions: Regeneration after the fire was established with a low but constant number of species, indicating a tendency towards vegetation resilience. This information allows government institutions to make better decisions on the management and prevention of these ecosystems in Mexico.

Keywords: Conservation, Resilience, Richness, Vegetation composition, Forest fires.

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INTRODUCTION

The Yucatan Peninsula has one of the regions with the largest area of tropical rainforests in Mexico (Islebe *et al.*, 2015). They are characterized by a very marked seasonality with a dominant floristic composition (Fabaceae), different structural patterns and a high rate of species turnover (β-diversity) (Hernández-Ramírez and García-Méndez, 2015). Despite their importance, they are considered threatened ecosystems due to the reduction of forest cover and the presence of hurricanes and forest fires (Trejo and Dirzo, 2002). In particular, the presence of forest fires causes alterations that directly affect the diversity and successional

dynamics of tropical forests (Martínez-Garza *et al.*, 2022). That is, after a fire, the natural regeneration process determines which trees will be replaced because many species are shade intolerant in their establishment stage and are therefore favored by the opening of clearings resulting from the impact of fire (Martínez and García, 2008). Although not all species respond in the same way to fire, they are subject to their regenerative strategies (Martínez-Garza *et al.*, 2022).

An adequate understanding of the restoration process requires information on various aspects, such as seed availability and viability, invasive species, plant succession, species phenology, among others (Harris *et al.*, 2006). Understanding these aspects is relevant to support restoration strategies for tropical rainforest ecosystems, for which continuous evaluations should be conducted to determine evidence that the succession dynamics tend to the restoration of these ecosystems (Gómez *et al.*, 2013). In this way, it is possible to define which aspects favor, which hinder and which restoration processes to choose at different stages of development of the plant community to determine whether it tends to resilience (Vargas, 2011). However, little is known about the restoration processes of medium superennifolia forest in the Yucatan Peninsula, which limits the success of the implementation of appropriate strategies for the restoration of ecosystems impacted by forest fires.

In this sense, extreme climatic changes such as forest fires occur with greater frequency and severity in tropical ecosystems, so the generation of knowledge from natural regeneration as the evaluation of changes in species diversity in different areas affected by fire in medium superennifolia forest becomes a priority issue (Hernández-Ramírez and García-Méndez, 2015). Therefore, the objective of this study was to evaluate the effect of fire on natural regeneration and forest species diversity in a medium superennifolia forest in southeastern Mexico. The information generated in this study will allow the promotion of different strategies that promote better decision making by government institutions to promote the prevention, management, and conservation of one of the most important biosphere reserves in Mexico.

MATERIALS AND METHODS

Sampling was conducted in the Muyil Core Zone of the Sian Ka'an Biosphere Reserve in Quintana Roo, Mexico (19° 59' 40.33" N - 87° 38' 18.3" W) (Figure 1). This area was impacted by a forest fire in the months of July and August 2019 affecting a total of 3,203.71 hectares, with the medium superennifolia forest being the most affected with 148.66 hectares according to the Comisión Nacional de Áreas Protegidas (CONANP, 2021).

Experimental design and biological material

In 2022 a paired experimental design was established with three burned and three unburnt forest sites. At each site, different categories of natural regeneration of post-wildfire vegetation were evaluated with 10 replicates respectively (n=60); a) circular sampling unit of 400 m^2 for adult trees (DBH>7.5 cm); b) three circular sub-sites of 5 m^2 for regeneration from 0 to 30 cm in height; c) three square sub-sites of 25 m^2 for medium regeneration from

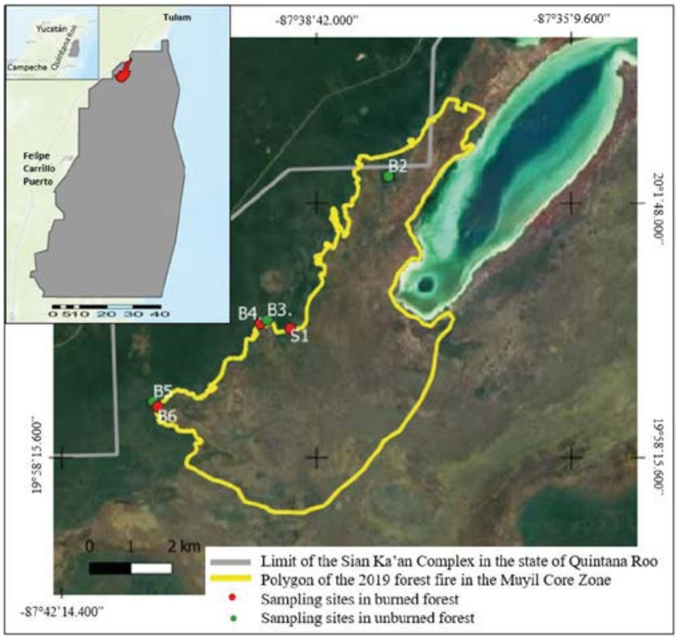

Figure 1. Location of sites for the evaluation of regeneration and forest species diversity in the Muyil Core Zone of the Sian Ka'an Biosphere Reserve.

31 cm to 1 m in height; and d) three square sub-sites of 64 m^2 for large regeneration from 1 to 3 m in height (Flores-Garnica *et al.*, 2018). In addition, the number of species at each site per regeneration level was recorded and botanical samples of the species were collected to identify them taxonomically with specialized keys that were validated in the World Flora Online database (WFO, 2023).

Abundance, richness and diversity species

Range-abundance curves were elaborated (Magurran, 1998), using the number of species and individuals per species recorded in each site (burned and unburnt forest), by regeneration level. The curves were plotted according to the logarithm base 10 of the proportion of each species (Log10 pi+1), and the data were ordered from the most abundant to the least abundant species. A nonparametric Wicolxon rank test was performed between sites by regeneration and trees. Species richness was assessed through rarefaction/extrapolation curve analysis (Chao and Jost, 2015). This analysis was done for each level of regeneration and trees between sites. Thus, curves were constructed from species abundance data considering 999 resamples (bootstrap). Specifically, the rarefaction/extrapolation curves defined a measure of completeness of the population, or community, belonging to the species included in the sample (Chao and Jost, 2015). Analyses were performed in iNEXT software (Hsieh *et al.*, 2016) available at https://chao.shinyapps.io/iNEXTOnline/. Finally, Shannon diversity indices (H'), Simpson dominance ($1/\lambda$) and Pielou's equality (J') were calculated, used to statistically contrast the values recorded between sites by regeneration and trees using the t-test (Zar, 1999). The analyses were conducted with PAST 4.6 software (Hammer *et al.*, 2001).

RESULTS AND DISCUSSION

Species composition and abundance

A total of 1193 individuals belonging to 69 species in 29 taxonomic families were recorded in the six study sites (Table 1). The families with the highest species richness were Fabaceae (15), Euphorbiaceae (6), Rubiaceae (6) and Spindaceae (5), while Arecaceae, Polygonaceae and Salicaeae only recorded 3 each. The first four families include 46%

Table 1. List of species recorded in the medium superennifolia forest of the Sian ka'an Biosphere Reserve in the burned forest (BF) and unburnt forest (UF) sites.

Family/species	0-30 cm		31cm-1 m		1-3 m		Trees	
	BF	UF	BF	UF	BF	UF	BF	UF
Acanthaceae								
Bravaisia berlanderiana (Ness.)	1		1	1	22			
Anacardiaceae								
Metopium brownei (Jacq) Urban.	14	11	31	3	12	1	3	37
Annonaceae								
Malmea depressa (Bailon) R. E. Fries.	2	2	6	6		13		
Mosannona depressa (Baill.) Chatrou		5	2	39	1	70		3
Apocynaceae								
Plumeria rubra L.						1		
Thevetia gaumeri Hemsl.		1	5		12	3	1	3
Araliaceae								
Dendropanax arboreus (L.)							1	
Arecaceae								
Desmoncus orthacanthos Mart.		3		1	2			
Mauritia flexuosa L. f.		2	1	3	6	26		
Thrinax radiata Lodd. ex Schult. & Schult. f.		3				8		
Burseraceae								
Bursera simaruba (L) Sarg.	1	1	20		45		7	38
Capparaceae								
Capparidastrum mollicellum (Standl.)				3	2	1		
Ebenaceae								
Diospyros cuneata Stand.		39	1	20	1	13		17
Ehretiaceae								
Ehretia tinfolia L.			2	2		2		
Euphorbiaceae								
Croton arboreus Millsp.		1	0	6		4	1	
Croton icche Lundell.	3	1	7	1			2	3
Gymnanthes lucida Sw.		1	1					
Jatropha subsect Gaumeri Dehgan.		1			2	2		
Sebastiania adenophora Pax & K. Hoffm.			1					
Fabaceae								
Bauhinia divaricata L.								1

Table 1. Continues...

Family/species	**0-30 cm**		**31cm-1 m 1-3 m Trees**					
	BF	**UF**	**BF**	**UF**	**BF**	**UF**	**BF**	**UF**
Caesalpinia gaumeri Greenm.		1		1	1	2		2
Caesalpinia pulcherrima (L.) Sw.				1		1		
Dalbergia granadillo Pittier								2
Desmodium incanum (Sw.) DC.			2		1			4
Enterolobium cyclocarpum (Jacq.) Griseb.					2			
Ficus mexicana (Miq.) Miq.			8		6			
Havardia albicans (Kunth) Britton & Rose					2			
Lonchocarpus rugosus Benth.		1	13	1	12			4
Lonchocarpus xuul Lundell			4		6	1		
Lonchocarpus yucatanensis Pittier		1		5		6		2
Lysiloma latisiliquum (L.) Benth			1		10		2	11
Piscidia piscipula (L.) Sarg.			1				1	7
Pithecellobium dulce (Roxb.) Benth.					1			
Senegalia gaumeri (S. F. Blake)					4		1	
Lamiaceae								
Vitex gaumeri Greenm.			4	3	17		3	11
Lauraceae								
Nectandra salicifolia (HBK) Nees.	9	12	33	25	20	12	2	
Malpighiaceae								
Bunchosia swartziana Griseb.				4		5		
Malvaceae								
Ceiba aesculifolia Britten & Baker f.	1							1
Hampea trilobata Standl.			1	2	2	1		
Moraceae								
Brosimum alicastrum Sw.			2				1	
Ficus crassinervia Desf. ex Willd.					2			
Myrtaceae								
Eugenia foetida M. Vahl		19	9	32	2	18		1
Myrcianthes fragrans (Sw.) McVaugh		1						
Phyllanthaceae								
Phyllantus micinianus Baill.					1			
Polygonaceae								
Coccoloba spicata Lundell		8		13		30		2
Neomillspaughia emarginata (H. Gross)				1		3		
Rumex obtusifolius L		2		7	3	7		
Putranjivaceae								
Drypetes laterifolia (Sw.) Krug & Urb.			1					
Rubiaceae								
Guettarda elliptica Sw.					1			1
Hamelia patens Jacq.		1	3		2			

Table 1. Continues...

Family/species	**0-30 cm**		**31cm-1 m 1-3 m Trees**					
	BF	**UF**	**BF**	**UF**	**BF**	**UF**	**BF**	**UF**
Psychotria pubescens Swartz.	1		1		2		2	
Randia aculeata L.						3		
Randia truncata Greenm. & C.H. Thomps.		1	1	1		2		
Rutaceae								
Esenbeckia pentaphylla Griseb.				1				
Zanthoxylum caribaeum Lam.			2	1	4		1	
Salicaceae								
Laetia thamnia L.			1					
Samyda yucatanensis Standl.				2				
Zuelania guidonia (Sw.) Britton & Millsp.					1		1	
Sapindaceae								
Allophylus cominia (L.) Sw.		1						
Cupania belizensis Standl.					8			
Melicoccus oliviformis (Radlk.) Acev. Rodr.							1	
Sapindus saponaria L.								2
Thouinia paucidentata Radlk.		5				1		3
Sapotaceae								
Chrysophyllum mexicanum Brandegee ex Standl.			1		1	1		
Manilkara zapota (L) Van Royen.				5	1	10	1	2
Simaroubaceae								
Simarouba glauca DC.		1			3	1		11
Solanaceae								
Nicotiana sect. Tabacum G. Don						1		
Solanum erianthum D. Don					5			
Urticaceae								
Cecropia obtusifolia Bertol.					5		2	

of the species recorded in the study, while only 22 families (76%) are represented by one or two species. In the burned forest sites, 461 individuals of 52 species belonging to 28 families were recorded. In contrast, in the unburnt forest sites, 732 individuals of 51 species belonging to 24 families were recorded. The families Urticaceae and Moraceae were recorded in the burned forest sites, while Malpighiaceae was recorded only in the unburnt forest sites.

The abundance of species recorded in the medium subperennial rainforest was different depending on the height category of the regeneration and the impact of fire. In the 0 to 30 cm regeneration the species *Diospyros cuneata* Stand., *Eugenia foetida* M. Vahl, *Nectandra salicifolia* (HBK) Nees and *Metopium brownei* (Jacq) Urban were the most abundant and dominant in unburnt forest sites ($z=-255.0$; $P<0.001$), only *M. brownei* and *N. salicifolia* were recorded in burned forest sites (Figure 2a, b). For the 31 cm to 1 m

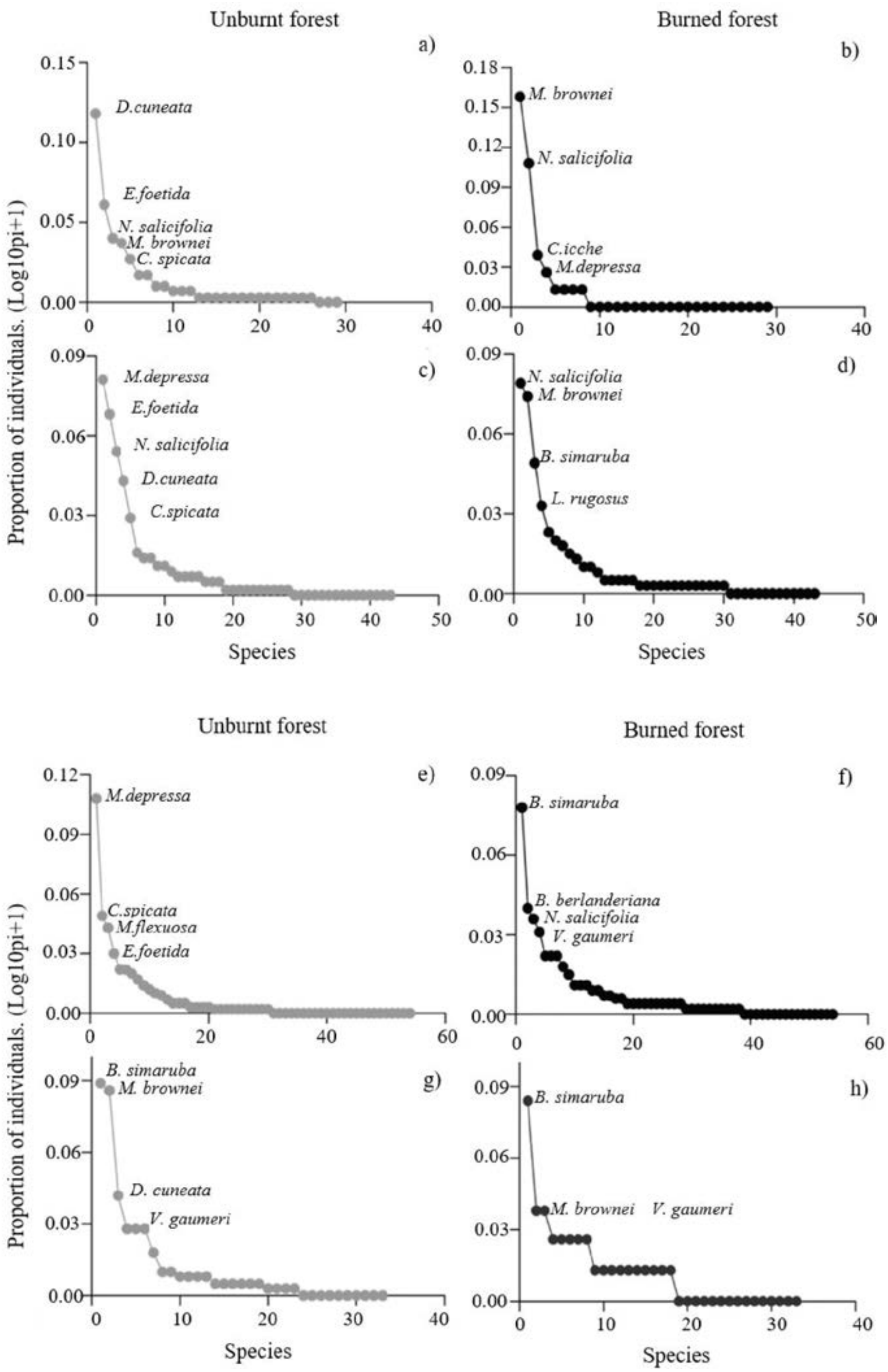

Figure 2. Range-abundance curves at different regeneration levels: a and b=0 to 30 cm, c and d=31 cm at 1 m, e and f=1 to 3 m, g and h=Trees in burned and unburnt forest sites, respectively.

renegeration the dominant species were *Mosannona depressa* (Baill.) Chatrou and *Eugenia foetida* M. Vahl as well as *N. salicifolia* and *M. brownei* for both sites (Figure 2c, d). In the 1 to 3 m regeneration, *Malmea depressa* (Bailon) R. E. Fries stands out with greater dominance in unburnt forest sites while *Bursera simaruba* (L) Sarg in burned forest sites

(Figure 2e, f). Finally, in the trees *B. simaruba* was the most dominant species in both sites (Figure 2g, h).

The Burseraceae, Lauraceae and Anacardiaceae families were found to be the most abundant in the burned forest sites with the presence of *B. simaruba*, *N. salicifolia* and *M. brownei* species, respectively. It has been reported that *M. brownei* is a species that persists after fire disturbance due to its resprouting capacity that makes it a dominant species in post-fire regeneration in tropical rainforests (Wolfe, 2009). Similarly, *B. simaruba* and *N. salicifolia* are species that manage to persist after fire due to their characteristics such as physical seed dormancy, stem thickness and the presence of rhizomes that allow them to potentially adapt to fire, which favors their establishment as early successional species (Juárez and Rodríguez-Trejo, 2003). This coincides with Brokaw's (1984) report that fire generates changes in abiotic factors (humidity, temperature, and soil pH) and biotic factors (herbaceous cover and number of mammals) in tropical rainforests that influence successional dynamics (Rodríguez-Trejo *et al.*, 2019).

Richness species

Regeneration from 0 to 30 cm in unburnt forest sites presented the highest richness as revealed by the rarefaction curve that grew rapidly as a function of individuals in the sample, while burned sites presented the lowest abundance and species richness ($P>0.05$) (Figure 3a). In contrast, regeneration from 31 cm to 1 m and 1 to 3 m presented the highest abundance of individuals with similar species richness in unburned (S=32 and S=29) and burned (S=35, S=38) forest sites (Figure 3b, c). The trees presented higher abundance and richness in unburned sites (Figure 3d).

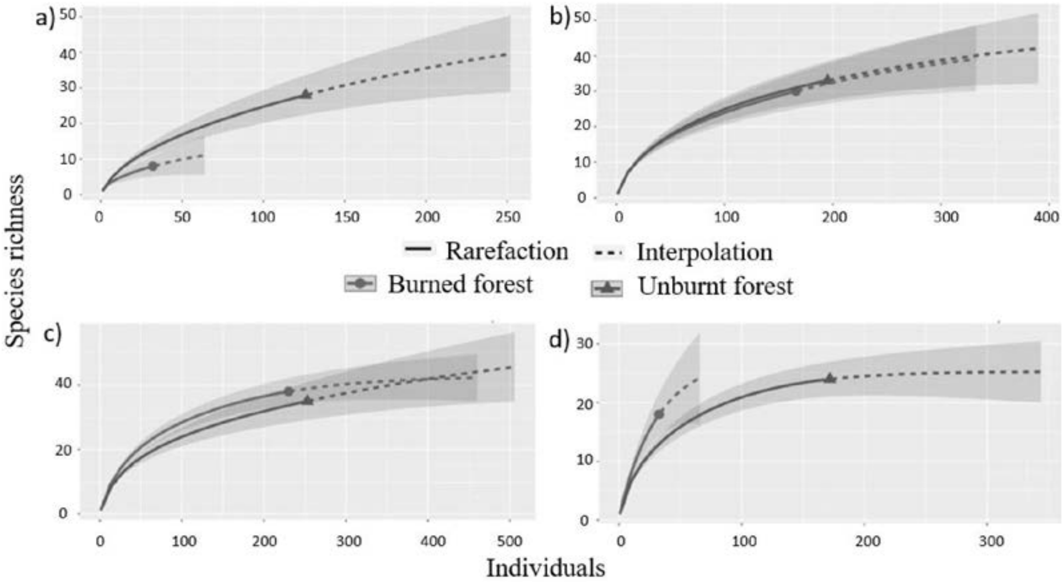

Figure 3. Rarefaction-extrapolation curves in categories a=0 to 30 cm, b=31 cm to 1 m, c=1 to 3 m and d=Trees. Solid line indicates interpolation and dotted line indicates extrapolation and the shadow shows the 95% confidence interval.

The consequences of forest fire on species richness in medium superennifolia forest were evident in burned and unburnt forest sites. However, changes at different levels of regeneration in the abundance and richness of the forest species community were highly variable. That is, species richness in the 0 to 30 cm regeneration was higher in the unburnt forest sites as revealed by the rarefaction curves. On the other hand, the regeneration from 31 cm to 1 m and 1 to 3 m showed similar abundance and species richness between sites, while the trees recorded higher abundance and richness in unburnt forest sites. The above suggests complex responses of forest species to fire related to adaptations to fire, but also to microclimatic conditions and seasonality of subperennial forests that influence the abundance and richness of the post-fire plant community (Ochoa-Franco *et al.*, 2019; Cadena-Zamudio *et al.*, 2022).

Species diversity and dominance

Regeneration from 0 to 30 cm recorded higher species diversity in unburnt forest sites ($t=4.3081$; $P<0.001$) (Figure 4a). Regeneration from 31 cm to 1 m had high diversity values with no significant differences between sites ($P>0.05$). In contrast, regeneration from 1 to 3 m recorded the highest diversity value in burned forest sites ($t=-3.9905$; $P<0.001$) (Figure 4a). Likewise, the trees in burned forest sites registered high diversity values, but without significant differences ($P>0.05$). The dominance of the regeneration from 0 to 30 cm recorded higher values in burned forest sites while the regeneration from 1 to 3 m and the tree stand recorded the lowest dominance values in burned forest sites (Figure 4b). With respect to evenness, values between 0.7 and 0.85 were observed in burned and unburnt forest sites, respectively (Figure 4b).

Changes in species diversity were found in the different regeneration categories, for example, regeneration from 1 to 3 m was more diverse in burned forest sites, contrary to what has been reported by other studies where more regeneration has been found in smaller categories (Rodríguez-Trejo *et al.*, 2019; Flores-Rodríguez *et al.*, 2021). This

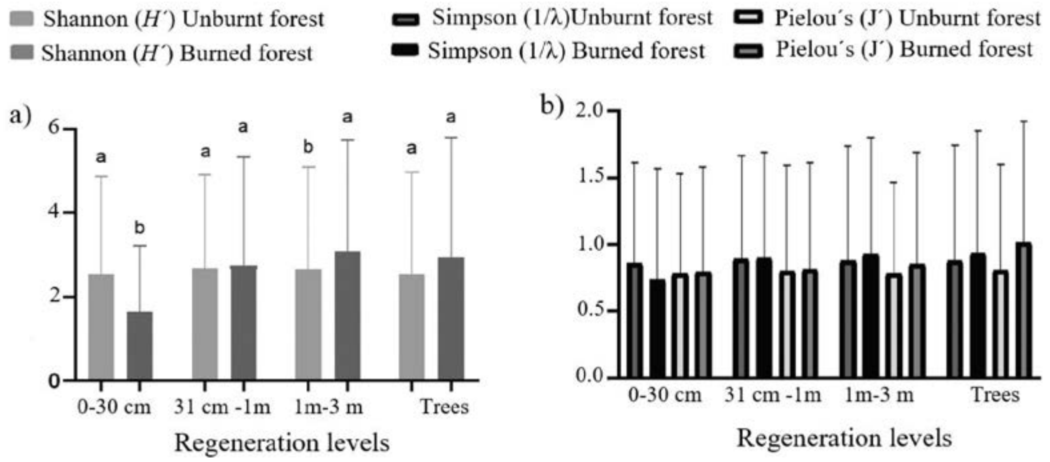

Figure 4. a=Shannon's Diversity Index (H') and b=Simpson's dominance ($1/\lambda$) and Pielou's evenness (J') at diverse levels of regeneration in burned and unburnt forest sites. Different letters represent significant differences ($P<0.05$).

could be related to the time elapsed since the beginning of the fire, which influenced the growth and adaptation of species in categories 1 to 3 m (Martínez and Álvarez, 1995). For various forest species of medium superennifolia forest, the opening of the canopy implies better conditions for natural succession, *i.e.*, fire creates suitable beds for the repopulation of species that establish more easily on the mineral soil, eliminating the physical barrier that understory plants represent and temporarily reducing competition for seedlings, which favors certain functional attributes such as rhizomes to act benefiting establishment and growth (Keeley, 2012). On the other hand, Simpson's dominance showed that in unburnt forest sites the species remained very similar in all categories of regeneration and in the trees (Giraldo-Cañas, 2000). In contrast, the smallest regeneration from 0 to 30 cm in burned forest sites was dominated by few species with the highest value, while the regeneration from 1 to 3 m with low dominance values, indicating that there is little probability that two random individuals belong to the same species (Salmerón *et al.*, 2017). With respect to evenness, similar values were observed in all regeneration height categories regardless of whether they were burned or unburnt forest sites (López-Jiménez *et al.*, 2019).

CONCLUSIONS

The results suggest that the vegetation of the medium superennifolia forest presented mechanisms to regenerate showing a capacity to recover from the impacts of fire. However, the environmental conditions after fire disturbance may in turn limit the tendency of ecosystem recovery, restricting new regeneration, so it is important to maintain permanent sites to monitor ecosystem recovery and thus be able to establish restoration management strategies for these ecosystems.

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